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An experimental study of friction of water in pipes

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AN EXPERIMENTAL STUDY OF FRICTION OF WATER IN PIPES

BY

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This is to certify that the thesis prepared in the Department of Theoretical and Applied Mechanics by CLIFFORD ERIK JOSEPH ERIKSON entitled An Experimental Study of Friction of Water in Pipes is approved by me as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

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E X P E R I M E N T A L S T U D Y
O F
F R I C T I O N O F W A T E R I N P I P E S.

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C O N T E N T S.

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I. INTRODUCTION.

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The importance of loss of head due to the friction of water in pipes and the limited amount of available data on tests for loss of head upon which formulas and tables are based, seem to justify a study along this line.

Information in regard to the friction loss of water in the pipe upon which the experiments for this thesis were made is not reliable on account of several bends and poor methods for measuring the loss of head.

This study embodied the design of apparatus, whereby these variables might be eliminated or reduced to a minimum, as well as the taking of data to verify previous experiments. Lack of time prevented taking up many interesting phases of the work and no attempt was made to find the effect of change of length or diameter of the pipe, or the change of temperature or the effect of the roughness of the inner surface. The work covered, primarily deals with the effect of the velocity upon friction loss, with special attention paid to the losses near the critical velocity.

II. THEORY.

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Friction loss is the most important factor affecting the discharging capacity of pipe lines, since other losses are commonly small in comparison with it.

Several attempts have been made to express friction loss of head by means of a simple and accurate formula, but due to the great variations in several of the terms which it depends upon, this formula seems almost impossible. For a straight pipe of a given kind and loss in a given length, the friction loss of head varies chiefly with the diameter and velocity of flow. But there are also other factors which enter in, and most careful experiments made with pipes, show that the so-called friction loss is materially influenced by factors which cannot be controlled by the experimenter, and which in the practical use of pipes are sure to vary. One of these factors is temperature. Another is the character of the pipe surface which may vary from month to month or even from day to day, enough to appreciably change the loss of head due to a given velocity. It therefore seems futile to seek a single general formula by which the friction loss in any proposed pipe line can be predicted with great accuracy.

Considering a fluid flowing over the surface of a solid body, the frictional force per unit area is found to be independent of the pressure and to vary approximately as the square of the velocity of flow, except for quite small velocities. It also varies nearly in direct ratio with the velocity of flow if this is very small. Applying these principals to a pipe,

$F = a' v_1 + b' v_1^2$, where

F = total sum of friction losses.

v_1 = surface velocity.

a' and b' = coeficients.

Assuming v_1 to vary directly with v, and substituting the above value of F, in the equation for lost head,

$H^1 = \frac{1}{r}$ F (v), we get

$$H^1 = \frac{1}{r} (av + bv^2) \text{ - - - - - - - - - - - - - (1)}$$

where H^1 = lost head due to length l of pipe

and r = radius of pipe.

Using formula (1) Darcy found by experimenting that the coeficients a & b varied greatly with the character of the pipe surface and also with the diameter. Then for pipes in practical use, he recommends the following formula as sufficiently correct for the range of velocities which ordinarily exist.

$$H^1 = \frac{1}{r} b_1 v^2 \text{ - (2)}$$

Another way of expressing Darcy's formula is as follows:

$$H^1 = f \frac{l}{d} \frac{v^2}{2g} \text{ - - - - - - - - - - - - - - - - - - - (3)}$$

where d = diameter of pipe

g = 32.16 ft./sec./sec.

From this formula Chezy developed his formula which is considered good, but is mostly used in the discussion of flow in open channels, and is as following:-

Solving for v in (3) writing $s = \frac{H^1}{l}$, and introducing a new coefficient c such that

$$c = \sqrt{\frac{8g}{f}}$$

we have

$$v = c\sqrt{rs}$$

These formulas given are the simplest, and are also the most reliable formulas in use at the present time.

III. DESCRIPTION OF APPARATUS.

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The pipe experimented upon is located at a distance of about three ft. from the upper part of the North wall in the Hydraulics Laboratory at the University of Illinois. Valves are so arranged on it that the water can be shut off near the stand pipe or at the free end of the pipe. The total length of this pipe is about 230 ft. The pipe is divided into about three and one half lengths, each length dropped one foot below the other, and connected by a piece of straight pipe and two 90° bends. To avoid these bends, a length of straight pipe 56 ft. 3 in. long was tapped off, this allowing a distance of a little more than 10 ft. from the bends to the end of the length of pipe considered. On this length there was contained on flange joint. This steel pipe has an inside diameter of exactly 2-3/32 inches. Its diameter was obtained by the following method:- Along the pipe at intervals of unequal distances have been bored in, small holes for the purpose of obtaining pressures at different intervals along the line of pipe. These holes have been bored directly opposite each other and are tightly closed by means of small screw plugs. Removing two of the directly opposite screws, a semi-cylindrical stick was inserted and wedges driven in on each side until a very deep impression was made. From this impression the inside diameter could very readily be measured. This proved very satisfactorily as in three consecutive measurements the results were the same.

The quantity of water was measured by allowing it to be discharged into a tank upon a platform scale, the weight and time being recorded simultaneously. This tank having a utilized

capacity of 17000 lb.

The method of measuring pressures was by an inverted U-tube, which was about one-half filled with air. The loss of head being measured directly by the difference in the water columns. This pressure gauge is shown with all its dimensions and connections to the pipe in Fig. (1)

The pipe was tapped at A & B and a 3/4 in. pipe connected. A view of the connection is given above A in Fig. (1). This small pipe was carried parallel to the large pipe, sloping slightly downward as it approached the pressure gauge, so as to eliminate all possible chances of allowing air to remain in the pipe. From B a 3/4 in. pipe was connected to the pressure gauge. By this means it was possible for one man to read to lost head directly, this advantage being that the difference in heads were read at the same time, eliminating as many errors in the determining of lost head as possible.

III. DESCRIPTION OF METHOD.

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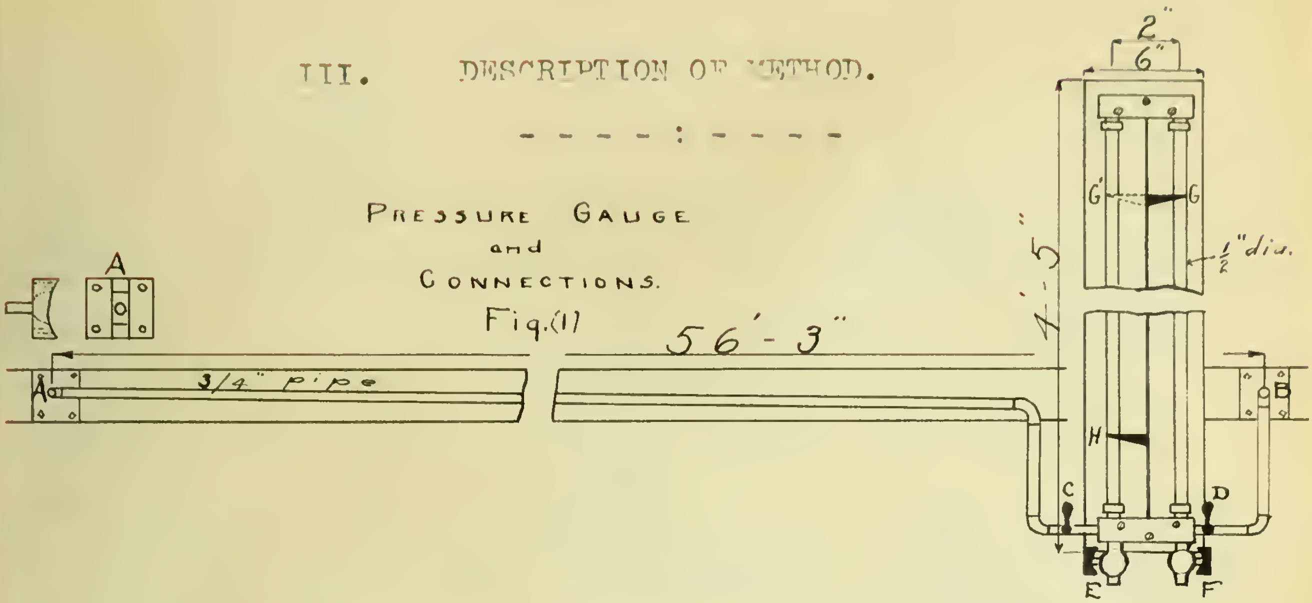
PRESSURE GAUGE and CONNECTIONS.

Fig.(1)



At the beginning of the experiment all valves were opened wide, except the ones at E and D on the pressure gauge, these being closed to allow the water to force its way through the gauge and out at the valve F, carrying with it all the air that was in the pipe. After allowing the water to discharge freely from three to five minutes, the valves at C and F were closed, while those at D and E were opened, thus permitting the air to be driven from the pipe BD. Both valves at E and F were then opened and those at C and D closed, allowing the water to be drained from the gauge. Closing the valves at E and F and opening those at C and D, the water rose in the glass tubes to their respective heights. Setting the pointers G and H at the levels of the water column and swinging G to G', the difference of the water levels measured in feet gave the lost head for that length of pipe directly.

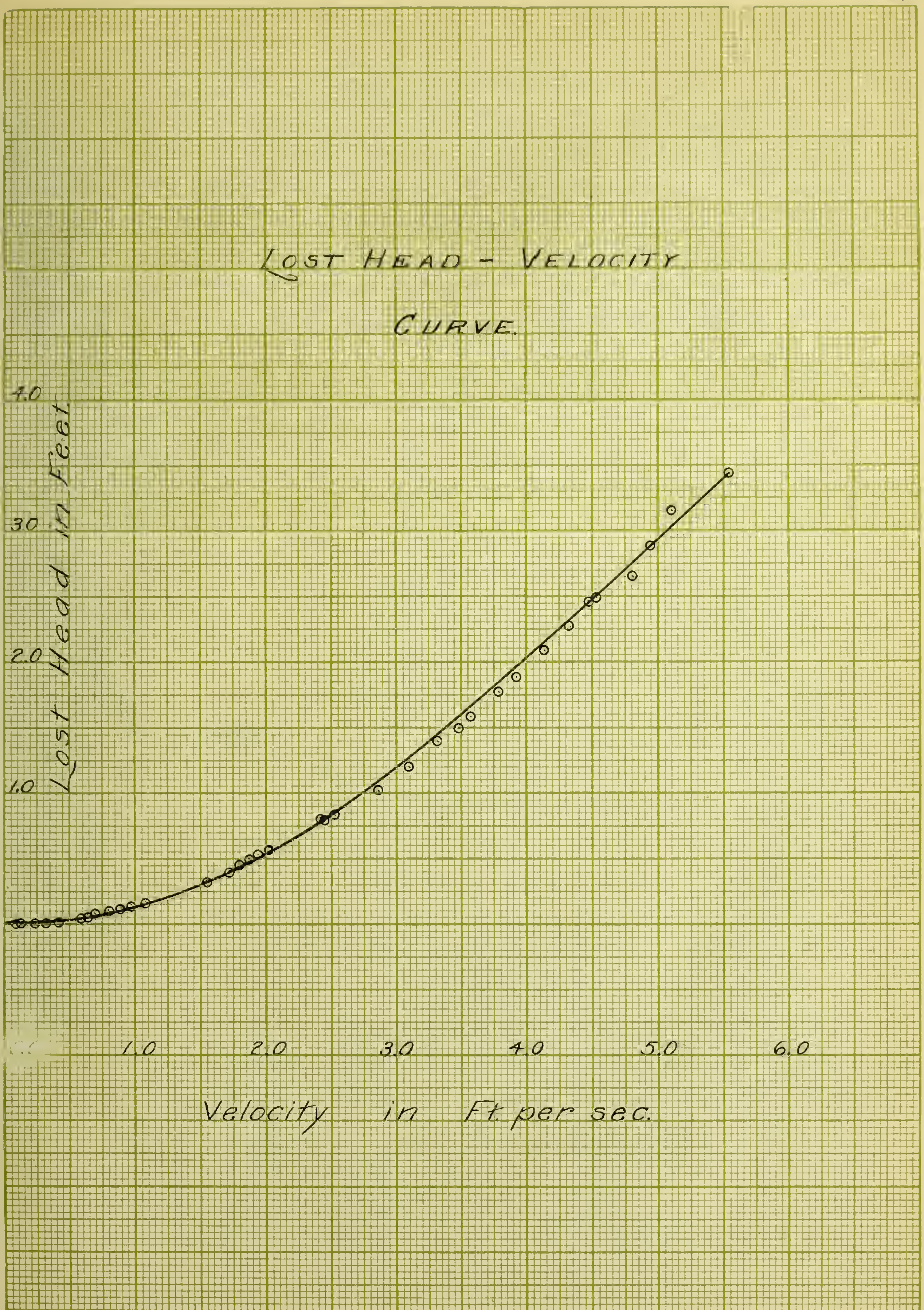
In order to guard against repetition of the same velocity of flow through the pipe the valve at the free end of the pipe was so manipulated as to give a definite lost head each time as read from the pressure gauge. The lowest possible reading of lost head was taken and varied to as high values as was possible for

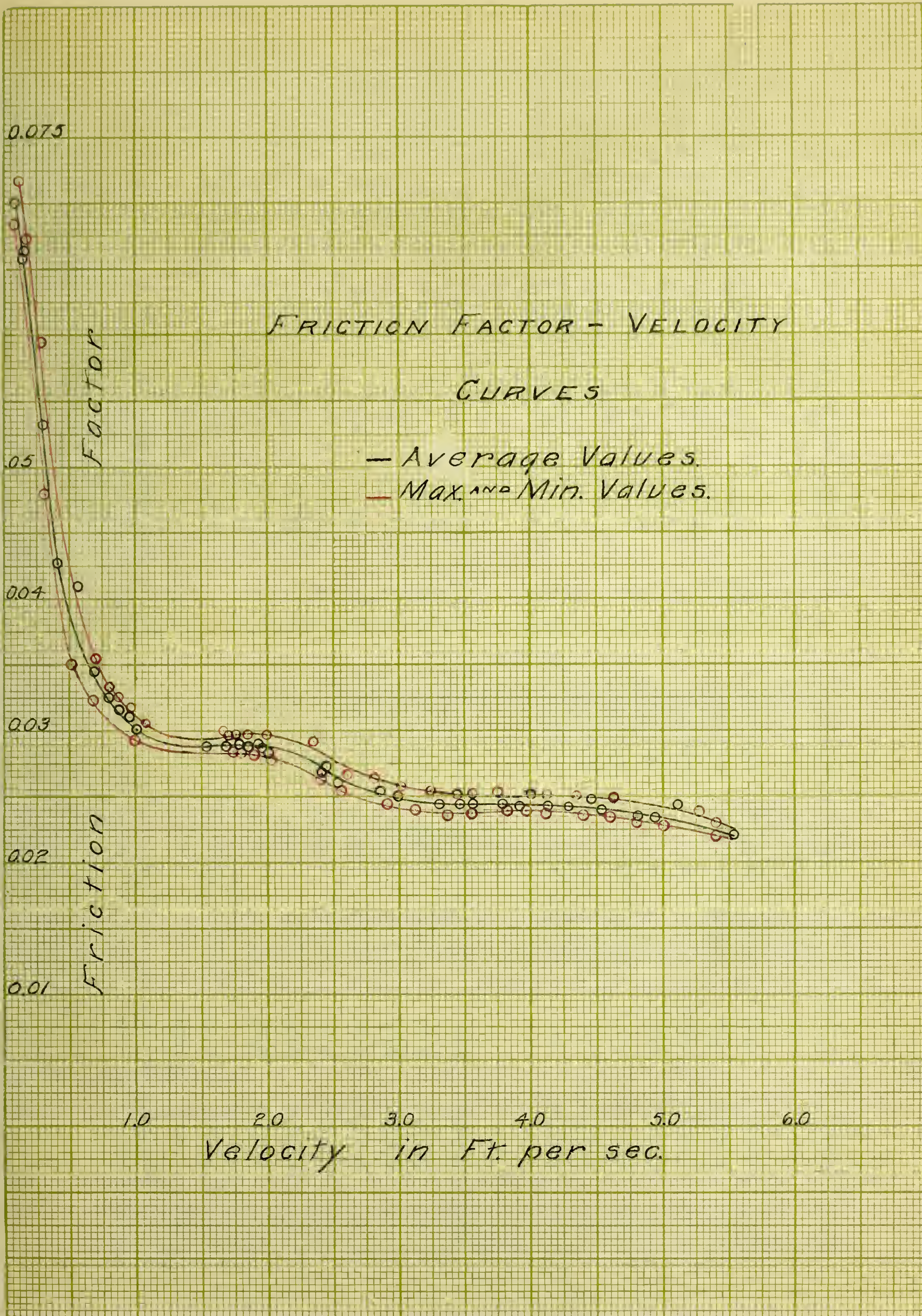
the pressure gauge to be read. Several repetitions were made, however, where indefinite or inaccurate results seem to prevail.

When the lost head had been fixed, the valve on the measuring tank was closed and weights placed on the beam of the scale to over balance the water remaining in the tank, which could not be removed. As the beam raised the initial time was taken and a certain known weight then placed upon the beam of the scale. The lost head was then checked, and the final time caught as the water balanced the known weight.

Having experimentally obtained the weight of the water, time and lost head; the friction factor was obtained substituting the required values in the formula given in the Theory.

Six readings were taken before the velocity of flow was changed. This giving the average of six readings to determine one point on the curves.


Lost Head – Velocity
Curve.
Lost Head in Feet
4.0
3.0
2.0
1.0
1.0
2.0
3.0
4.0
5.0
6.0
Velocity in Ft per sec.



FRICTION FACTOR - VELOCITY
CURVES
— Average Values.
— Max. AND Min. Values.
Friction Factor
0.075
0.05
0.04
0.03
0.02
0.01
1.0
2.0
3.0
4.0
5.0
6.0
Velocity in Ft. per sec.

DATA

No	Lost Head in Feet	Wt of Water in lb.	Time in Sec's.	Velocity in Ft. per sec.	Friction Factor (f)
1	.0026	20	159	.085	.0718
2	.0026	20	153	.089	.0670
3	.0026	20	155	.087	.0685
4	.0026	20	159	.085	.0718
5	.0026	20	158	.085	.0713
6	.0026	20	158	.085	.0713
AV.	.0026	20	157	.086	.0703
1	.0052	50	270	0.124	.0672
2	.0052	50	264	0.127	.0644
3	.0052	50	269	0.126	.0672
4	.0052	50	267	0.126	.0672
5	.0052	50	264	0.127	.0644
6	.0052	50	268	0.126	.0672
AV.	.0052	50	267	0.126	.0665

No	Lost Head in Feet	Wt. of Water in lb.	Time in Sec's.	Velocity in Ft. per sec.	Friction Factor (f)
1	.0052	50	270	0.124	.0672
2	.0052	50	271	0.124	.0672
3	.0052	60	326	0.124	.0672
4	.0052	40	214	0.126	.0650
5	.0052	50	264	0.127	.0644
6	.0052	50	266	0.126	.0650
AV.	.0052	50	268	0.125	.0658
1	.0104	100	287	0.235	.0376
2	.0104	100	287	0.235	.0376
3	.0104	100	287	0.235	.0376
4	.0104	100	289	0.233	.0382
5	.0104	100	289	0.233	.0382
6	.0104	100	287	0.235	.0376
AV.	.0104	100	288	0.234	.0378

DATA

No	Lost Head in Feet	Wt. of Water in lb.	Time in Sec's.	Velocity in Ft per sec	Friction Factor (f)
1	.0260	40	82	0.329	.0480
2	.0260	40	83	0.325	.0490
3	.0260	40	83	0.325	.0480
4	.0208	30	64	0.315	.0562
5	.0208	40	88	0.306	.0595
6	.0208	40	88	0.306	.0595
AV.	.0234	38	81	0.318	.0533
1	.1041	200	204	0.660	.0432
2	.0833	200	218	0.618	.0432
3	.0625	200	251	0.538	.0430
4	.0573	200	262	0.513	.0434
5	.0521	300	402	0.505	.0406
6	.0469	300	392	0.517	.0350
AV.	.0675	233	290	0.588	.0411

No	Lost Head in Feet	Wt. of Water in lb.	Time in Sec's.	Velocity in Ft per sec.	Friction Factor (f)
1	.0365	50	81	0.416	.0420
2	.0365	50	80	0.420	.0412
3	.0365	50	82	0.411	.0430
4	.0365	50	82	0.411	.0430
5	.0365	50	83	0.405	.0442
6	.0365	50	82	0.411	.0430
AV.	.0365	50	82	0.412	.0427
1	.0833	200	190	0.710	.0328
2	.0729	200	200	0.673	.0318
3	.0729	200	213	0.662	.0330
4	.0521	200	230	0.584	.0302
5	.0469	200	253	0.534	.0328
6	.0500	200	218	0.618	.0261
AV.	.0630	200	217	0.630	.0311

DATA

No	Lost Head in Feet	Wt. of Water in lb.	Time in Sec's.	Velocity in Ft. per sec.	Friction Factor (f)
1	.0833	100	98	0.689	.0352
2	.0833	100	96	0.701	.0338
3	.0781	200	195	0.689	.0352
4	.0781	100	97	0.693	.0324
5	.0781	100	98	0.689	.0352
6	.0781	100	98	0.689	.0352
AV.	.0798	117	114	0.691	.0345
1	.1042	100	85	0.794	.0329
2	.1042	100	81	0.832	.0300
3	.1042	100	86	0.786	.0332
4	.1042	100	85	0.794	.0329
5	.1042	100	85	0.794	.0329
6	.1042	100	86	0.786	.0332
AV.	.1042	100	85	0.798	.0325

No	Lost Head in Feet	Wt of Water in lb.	Time in Sec's.	Velocity in Ft. per sec.	Friction Factor (f)
1	0.125	100	74	0.912	.0311
2	0.125	200	152	0.887	.0316
3	0.125	100	74	0.912	.0311
4	0.125	200	154	0.874	.0326
5	0.125	200	152	0.887	.0316
6	0.125	100	76	0.887	.0316
AV.	0.125	150	130	0893	.0316
1	0.146	200	139	0.971	.0306
2	0.146	200	140	0.962	.0312
3	0.146	200	139	0.971	.0306
4	0.146	200	140	0.962	.0312
5	0.146	200	140	0.962	.0312
6	0.146	200	138	0.975	.0318
AV.	0.146	200	141	0.969	.0311

DATA

No	Lost Head in Feet	Wt. of Water in lb.	Time in Sec's.	Velocity in Ft. per sec.	Friction Factor (f)
1	0.177	200	125	1.076	.0302
2	0.177	200	125	1.076	.0302
3	0.173	200	126	1.071	.0300
4	0.173	200	126	1.071	.0300
5	0.173	200	127	1.063	.0304
6	0.173	200	126	1.071	.0300
AV.	0.174	200	126	1.071	.0301
1	0.344	100	43	1.570	.0278
2	0.344	100	44	1.530	.0293
3	0.344	100	44	1.530	.0293
4	0.344	100	43	1.570	.0278
5	0.344	200	89	1.520	.0297
6	0.344	200	89	1.520	.0297
AV.	0.344	133	59	1.540	.0289

No	Lost Head in Feet	Wt. of Water in lb.	Time in Sec's.	Velocity in Ft. per sec.	Friction Factor (f)
1	0.417	200	79	1.710	.0284
2	0.417	200	79	1.710	.0284
3	0.417	200	79	1.710	.0284
4	0.427	200	80	1.680	.0300
5	0.427	200	78	1.730	.0284
6	0.427	200	79	1.710	.0290
AV	0.422	200	79	1.710	.0288
1	0.547	500	172	1.958	.0282
2	0.542	500	176	1.916	.0292
3	0.542	500	173	1.945	.0284
4	0.552	500	171	1.966	.0284
5	0.542	500	174	1.937	.0292
6	0.542	500	175	1.924	.0316
AV.	0.544	500	174	1.941	.0291

DATA

No	Lost Head in Feet	Wt. of Water in lb.	Time in Sec's.	Velocity in Ft. per sec.	Friction Factor (f)
1	0.464	100	38	1.78	.0291
2	0.464	300	114	1.76	.0297
3	0.464	200	75	1.80	.0285
4	0.458	200	75	1.80	.0283
5	0.458	200	76	1.76	.0294
6	0.458	200	76	1.76	.0294
AV.	0.461	200	76	1.78	.0291
1	0.500	200	72	1.87	.0285
2	0.500	200	73	1.85	.0291
3	0.500	200	73	1.85	.0291
4	0.505	200	73	1.85	.0294
5	0.505	200	72	1.87	.0287
6	0.505	200	71	1.89	.0282
AV.	0.503	200	72	1.86	.0288

No	Lost Head in Feet	Wt. of Water in lb.	Time in Sec's.	Velocity in Ft. per sec	Friction Factor (f)
1	0.542	200	68	1.98	.0275
2	0.542	200	69	1.95	.0284
3	0.542	200	68	1.98	.0275
4	0.552	200	69	1.95	.0284
5	0.552	200	69	1.95	.0284
6	0.552	200	69	1.95	.0284
AV.	0.547	200	69	1.96	.0281
1	0.547	200	69	1.95	.0287
2	0.547	200	69	1.95	.0287
3	0.547	200	68	1.98	.0279
4	0.547	200	69	1.95	.0287
5	0.547	200	68	1.98	.0279
6	0.547	200	68	1.98	.0279
AV.	0.547	200	69	1.97	.0285

DATA

No	Lost Head in Feet	Wt. of Water in lb.	Time in Sec.'s	Velocity in Ft. per sec.	Friction Factor (f)
1	0.583	200	68	1.98	.0296
2	0.583	200	66	2.04	.0279
3	0.583	200	66	2.04	.0279
4	0.583	200	66	2.04	.0279
5	0.583	200	66	2.04	.0279
6	0.583	200	66	2.04	.0279
AV.	0.583	200	66	2.03	.0282
1	0.813	700	196	2.341	.0295
2	0.813	1000	253	2.663	.0229
3	0.791	700	197	2.395	.0273
4	0.791	800	214	2.403	.0273
5	0.813	700	196	2.341	.0295
6	0.791	700	197	2.395	.0273
AV.	0.802	767	209	2.423	.0268

No	Lost Head in Feet	Wt. of Water in lb.	Time in Sec.'s.	Velocity in Ft. per sec.	Friction Factor (f)
1	0.823	500	138	2.441	.0275
2	0.823	700	194	2.433	.0310
3	0.823	500	143	2.357	.0294
4	0.813	800	212	2.429	.0274
5	0.791	1000	280	2.403	.0237
6	0.823	600	167	2.420	.0280
AV.	0.816	685	189	2.414	.0278
1	0.802	200	55	2.45	.0267
2	0.791	400	134	2.01	.0389
3	0.791	600	139	2.91	.0186
4	0.791	200	55	2.45	.0263
5	0.791	200	55	2.45	.0263
6	0.791	200	55	2.45	.0263
AV.	0.793	300	82	2.45	.0274

DATA

No	Lost Head in Feet	Wt. of Water in lb.	Time in Sec's.	Velocity in Ft. per sec.	Friction Factor (f)
1	0.839	600	161	2.51	.0265
2	0.833	400	106	2.54	.0257
3	0.833	200	53	2.55	.0255
4	0.828	400	107	2.52	.0260
5	0.828	200	53	2.55	.0254
6	0.828	500	134	2.51	.0262
AV.	0.832	383	102	2.53	.0259
1	1.063	200	46	2.93	.0247
2	1.052	500	117	2.88	.0253
3	1.052	500	118	2.86	.0251
4	1.052	200	47	2.87	.0255
5	1.037	200	47	2.87	.0251
6	1.037	400	96	2.81	.0261
AV.	1.049	333	79	2.87	.0254

No	Lost Head in Feet	Wt. of Water in lb	Time in Sec's.	Velocity in Ft. per sec.	Friction Factor (f)
1	1.188	200	43	3.13	.0241
2	1.198	700	153	3.09	.0251
3	1.203	500	110	3.06	.0257
4	1.208	200	43	3.13	.0250
5	1.214	500	110	3.06	.0260
6	1.203	400	87	3.10	.0250
AV.	1.203	417	91	3.09	.0251
1	1.344	200	40	3.37	.0235
2	1.339	400	83	3.25	.0251
3	1.333	500	103	3 27	.0250
4	1.339	200	37	3.65	.0200
5	1.339	400	86	3.13	.0273
6	1.339	500	104	3.24	.0255
AV.	1.339	367	76	3.32	.0244

DATA

No	Lost Head in Feet	Wt. of Water in lb.	Time in Sec's.	Velocity in Ft. per sec.	Friction Factor (f)
1	1.495	200	38	3.55	.0237
2	1.490	700	137	3.45	.0250
3	1.490	600	116	3.48	.0245
4	1.500	200	39	3.46	.0250
5	1.500	500	96	3.51	.0243
6	1.495	600	117	3.45	.0251
AV.	1.495	467	91	3.48	.0246
1	1.573	200	39	3.46	.0261
2	1.563	600	113	3.58	.0243
3	1.563	600	114	3.55	.0247
4	1.599	200	37	3.65	.0240
5	1.583	700	133	3.55	.0251
6	1.583	300	56	3.61	.0243
AV.	1.577	433	82	3.57	.0247

No	Lost Head in Feet	Wt. of Water in lb.	Time in Sec's.	Velocity in Ft per sec	Friction Factor (f)
1	1.745	200	36	3.75	.0247
2	1.766	900	159	3.82	.0241
3	1.797	500	88	3.79	.0250
4	1.797	200	36	3.75	.0253
5	1.766	900	159	3.82	.0241
6	1.776	900	160	3.79	.0245
AV.	1.769	600	90	3.79	.0246
1	1.902	200	34	3.97	.0240
2	1.880	800	138	3.91	.0245
3	1.870	600	103	3.92	.0241
4	1.875	600	104	3.89	.0247
5	1.902	700	120	3.94	.0245
6	1.870	600	103	3.92	.0241
AV.	1.886	583	100	3.93	.0243

DATA

No	Lost Head in Feet	Wt. of Water in lb.	Time in Sec's.	Velocity in Ft. per sec.	Friction Factor (f)
1	2.063	200	32	4.22	.0231
2	2.073	600	99	4.08	.0250
3	2.083	600	97	4.17	.0240
4	2.078	200	34	4.00	.0261
5	2.099	800	130	4.15	.0243
6	2.099	500	130	4.22	.0237
AV.	2.082	483	87	4.14	.0243
1	2.250	200	32	4.22	.0251
2	2.229	600	94	4.30	.0247
3	2.276	800	125	4.32	.0243
4	2.290	200	30	4.50	.0225
5	2.266	600	95	4.26	.0250
6	2.271	600	92	4.39	.0235
AV.	2.265	500	78	4.33	.0242

No	Lost Head in Feet	Wt. of Water in lb.	Time in Sec's.	Velocity in Ft. per sec.	Friction Factor (f)
1	2.438	200	31	4.35	.0257
2	2.495	1500	221	4.58	.0247
3	2.495	1500	221	4.58	.0247
4	2.438	200	31	4.35	.0257
5	2.438	200	31	4.35	.0257
6	2.495	1500	221	4.58	.0247
AV.	2.466	850	126	4.47	.0252
1	2.406	200	31	4.35	.0253
2	2.510	1500	219	4.62	.0250
3	2.531	500	74	4.55	.0243
4	2.516	1200	176	4.60	.0237
5	2.490	500	75	4.49	.0245
6	2.479	1200	177	4.57	.0237
AV.	2.489	850	125	4.53	.0244

DATA

No	Lost Head in Feet	Wt. of Water in lb.	Time in Sec's.	Velocity in Ft. per sec.	Friction Factor (f)
1	2.646	500	71	4.74	.0235
2	2.625	900	128	4.74	.0233
3	2.630	500	62	4.68	.0240
4	2.646	1100	157	4.72	.0237
5	2.661	500	70	4.81	.0230
6	2.677	1000	142	4.75	.0235
AV.	2.648	750	105	4.81	.0235
1	2.906	500	67	5.03	.0230
2	2.849	1200	165	4.90	.0237
3	2.833	500	69	4.88	.0237
4	2.859	1200	164	4.93	.0235
5	2.917	500	68	4.95	.0237
6	2.906	1000	135	4.99	.0233
AV.	2.878	817	111	4.95	.0235

No	Lost Head in Feet	Wt. of Water in lb.	Time in Sec's.	Velocity in Ft. per sec.	Friction Factor (f)
1	3.109	400	52	5.18	.0231
2	3.099	1100	142	5.18	.0230
3	3.120	400	52	5.17	.0233
4	3.146	1100	143	5.18	.0233
5	3.245	400	50	5.38	.0223
6	3.208	400	59	4.57	.0306
AV.	3.154	633	83	5.11	.0244
1	3.344	400	50	5.39	.0229
2	3.406	1100	137	5.42	.0206
3	3.458	400	43	6.27	.0175
4	3.495	1000	128	5.27	.0251
5	3.495	400	50	5.39	.0239
6	3.438	1100	135	5.49	.0227
AV.	3.439	733	94	5.54	.0221

Average Results of Data.

No	Lost Head in Feet	Velocity in Ft. per sec.	Friction Factor (f)
1	.0026	0.086	.0703
2	.0052	0.126	.0665
3	.0052	0.125	.0658
4	.0104	0.234	.0378
5	.0234	0.318	.0533
6	.0675	0.588	.0411
7	.0365	0.412	.0427
8	.0630	0.630	.0311
9	.0798	0.691	.0345
10	.1042	0.798	.0325
11	.1250	0.893	.0316
12	.1460	0.969	.0311
13	.1740	1.071	.0301
14	0.344	1.540	.0289
15	0.422	1.710	.0288
16	0.544	1.941	.0291
17	0.461	1.780	.0291
18	0.503	1.860	.0288
19	0.547	1.960	.0281
20	0.547	1.970	.0283
21	0.583	2.030	.0282
22	0.793	2.450	.0274
23	0.802	2.423	.0268
24	0.816	2.414	.0278
25	0.832	2.530	.0259
26	1.049	2.870	.0254
27	1.203	3.090	.0251
28	1.339	3.32	.0244
29	1.495	3.48	.0246
30	1.577	3.57	.0247
31	1.769	3.79	.0246
32	1.886	3.93	.0243
33	2.082	4.14	.0243
34	2.265	4.33	.0242
35	2.466	4.47	.0252
36	2.489	4.53	.0244
37	2.648	4.81	.0235
38	2.878	4.95	.0235
39	3.154	5.11	.0244
40	3.439	5.54	.0221

Length of pipe, 56 ft. 3 in's.
Inside diameter, $2\frac{3}{32}$ in's.
$f = 0.199 \frac{H'}{V^2}$

IV. DISCUSSION.

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As was previously stated in the theory, the results obtained for the friction factor cannot be taken as a very high degree of accuracy. There being so many variations and chances for errors, that the experimenter finds himself at sea to overcome them all and make his results fit all cases.

In the present results errors being eliminated as far as possible, yet slight chances for such were present.

By allowing the water to flow freely for 3 to 5 minutes before taking data the errors due to air bubbles in the pipes can readily be neglected, but the constant vibrating of the water level in the pressure gauge allowed a slight chance for errors. Connecting the pressure gauge as was done, made it possible to read the lost head direct, and allowed very little chance for errors in setting the pointers at each water level before they had varied any appreciable amount.

It was tried to have the longest straight pipe possible on this line of pipe without being hindered by the bends, but very little is known or could be found out as to the effect the bends had in varying the lost head. But it was thought that ten feet of straight, 2 in. pipe was sufficient to overcome any irregularity in the pressure due to bends in the pipe.

The temperature of the water varied from 71° F to 79° F keeping generally around 76° F as an average.

In changing the quantity of water from pounds to cubic feet, one pound was assumed equal to 62.35 cu. ft. at 62° F, allowing practically a constant variation in temperature from the assumed of 14° F.

The greatest chance for errors, however, was observed in catching the time it took a certain quantity of water to flow in to the measuring tank. The quantity divided by the product of the time and the cross-sectional area of the inside of the pipe gives the velocity of flow. This value when placed in the general formula for lost head has to be squared, which greatly increases the error.

Having varied the time one second in several cases, an error of 0.7% was calculated in the majority of cases tried, showing that the accuracy of the friction factor depended considerably upon the accuracy of the time.

As seen from the friction factor-velocity curve a marked peculiarity has occured around the velocity of 2.0 ft./sec. Several check readings were taken, but all were about the same with very slight variations. Apparently the curve seems to take the form shown, but no reasons or proofs except the experimental data can be given in its favor. According to Merriman's values, the points plotted should lie on a very smooth curve, which would practically fall mid-way between the points plotted, but due to the strong and even positions, which the points desire to hold, it seemed impossible to allow the curve to follow any other direction. The curve with the exception of this irregularity agree very well with values plotted from Merriman as will be shown in Table 1.

Of the six values recorded the maximum and minimum values are plotted with red ink; the average curve being shown between these in a black colored ink.

The values obtained for lost head, when plotted in a Lost Head- Velocity curve, show comparatively good results and

form the path of a very regular and smooth curve, varying slight at the velocities around 3 ft./sec. and above.

V. CONCLUSION.

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The results of the tests seem to indicate that the loss of head varies closely as the square of the velocity, except for low velocities. At these low velocities the relation of loss of head seems to bear no definite relation to the velocity.

The critical velocity or the velocity at which the lost head ceased to vary as the square of the velocity does not seem to be exactly defined. However the tests show it to be at a velocity of about 1.4 ft./sec. as shown on the friction factor-velocity curve.

The tests show results which compare very well with values as given in Merriman's text book on Hydraulics and also Hoskin's; a comparison of these results is shown in Table I.

TABLE I.

Velocity ft./sec.	Experimental	Merriman	Hoskin
1	.030	.034	.0298
2	.029	.029	
3	.026	.027	
4	.025	.026	
5	.024	.025	